PROJECT AUTHORIZATION NO. HWY- 2005-09

under

MASTER AGREEMENT FOR RESEARCH AND TRAINING SERVICES BETWEEN THE NORTH CAROLINA DEPARTMENT OF TRANSPORTATION AND NORTH CAROLINA STATE UNIVERSITY ON BEHALF OF THE INSTITUTE FOR TRANSPORTATION RESEARCH AND EDUCATION
(Contract No. 98-1783)

Project Title: Herbicide Options for Weed Management in the North Carolina Highway Wildflower Program

Formal Statement of Work: See attached proposal

Period of Performance: July 1, 2004 to June 30, 2007

Budget Authorization:

2005	2006	2007	Total
$52,298	$52,181	$54,966	$159,445

Property to be Furnished by the Department: None

Key Personnel: Alan C. York (P.I.) and Rick Seagroves (co-P.I.)

Project Monitor: Shannon Lasater, PE

Additional Terms and Conditions: Research Project Guidelines as posted on ITRE's website at *http://itre.ncsu.edu/research/ongoingguidelines.htm.*

IN WITNESS WHEREOF, the parties hereto have executed this Project Authorization as of

__________________________, 2003.

NORTH CAROLINA STATE UNIVERSITY

BY:_________________________________
Principal Investigator

BY:_________________________________
N. C. State University

BY:_________________________________
Director of ITRE

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

BY:_____________________________

FY 2005-2007

NCDOT

Research Proposal

Subcommittee:	Central Roadside Environmental Unit
Project Title:	Herbicide Options for Weed Management in The North Carolina Highway Wildflower Program
Submittal Date:	January 5, 2004
Organization:	North Carolina State University

Researcher:

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Executive Summary

The North Carolina Department of Transportation (NCDOT) Wildflower Program is one of the most successful, well known wildflower programs in the country. Besides promoting the state's $12 billion tourism industry and providing refreshing scenery for road-weary travelers, roadside plantings help control erosion, reduce mowing costs, and can increase driver alertness.

The wildflower species typically planted in the highly disturbed environment of a tilled bed are not very competitive with the aggressive weedy species that inhabit the state. Weeds are not only unsightly but they also compete with wildflowers for growth inputs and reduce wildflower stands, growth, and bloom production. Hence, control of weeds is a necessity in successful establishment and maintenance of wildflowers.

The most widely used weed control treatment for establishing wildflower beds in North Carolina has been soil fumigation, typically with the highly effective fumigant methyl bromide. This procedure is very expensive, and it necessitates the use of unsightly plastic tarping. Moreover, production of methyl bromide, classed as an ozone depleter, will cease at the end of 2004. The loss of methyl bromide will create a serious void in the weed management program for wildflowers. Chemical weed control (herbicides) is the only feasible means of managing weeds in roadside wildflower plantings in the absence of fumigation. There are no biological controls for weeds in wildflowers, and other non-chemical methods are much too labor intensive and costly. The NCDOT is currently using a limited number of herbicides in wildflowers, but the herbicides used do not control many weed species encountered. There are likely other herbicides that could be used safely and effectively, as demonstrated by preliminary experiments currently underway by this proposal's author, but very little is known about the tolerance of wildflowers to most herbicides and the weed control possible. Research in this area is a critical need. Further, such research is needed to support registration of herbicides that have potential uses in wildflowers. Considering the multi-species plantings common along roadsides and the number of annual and perennial weeds encountered, it is quite likely that suitable herbicides cannot be found to handle every situation. Hence, research is also needed to investigate new fumigants, such as methyl iodide, as an alternative to methyl bromide.

The proposed research will be designed to thoroughly investigate the use of herbicides and alternative fumigants in the establishment and maintenance of wildflowers. Results of the research will be used to develop weed management recommendations and educational programs for NCDOT personnel involved in wildflower management decisions.

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RESEARCH PLAN

I. Introduction

The North Carolina Department of Transportation (NCDOT) Wildflower Program began in 1985 as an integral part of highway beautification. Wildflowers are planted and maintained on approximately 3500 roadside acres in North Carolina by the Roadside Environmental Unit. This is one of the most successful, well known wildflower programs in the country (Warren, 2002). Besides promoting the state's $12 billion tourism industry (Anon. 2004) and providing refreshing scenery for road-weary travelers, roadside plantings help control erosion, reduce mowing costs, and can increase driver alertness (Anon., 2001). Studies have shown that use of wildflowers is a viable, economical, and environmentally sound alternative to traditional roadside vegetation management (Swan et al., 1993). Moreover, federal statutes require that a fraction of funds expended for any landscaping project undertaken on the Federal-aid highway system be used to plant wildflowers (Anon. 1998).

Many of the wildflower species planted on North Carolina's roadsides are non-native species selected for their display of colors. Attempts to establish wildflower meadows in roadside turf have generally been unsuccessful in the eastern United States, even in herbicide-suppressed turf (Kuhns et al., 1999). Hence, sites are thoroughly tilled when establishing wildflower plantings (NCDOT). When wildflower species are taken out of their native habitats and established in tilled areas along high-rights-of-way, they must compete with native weedy vegetation. The typically planted wildflower species generally are not very competitive with the aggressive weedy species that inhabit the state. Various winter annual weeds, such as vetch species, shepherd's-purse, Carolina geranium, Virginia pepperweed, horseweed, and cutleaf eveningprimrose can quickly invade fall plantings. Similarly, summer annual weeds, such as common lambsquarters, smartweed species, prickly sida, pigweed species, and various grass species invade wildflower plantings in the spring and summer. Various perennial weeds, such as curly dock, dogfennel, white clover, and hemp dogbane become problems in established wildflower beds. Weeds are not only unsightly but they also compete with wildflowers for growth inputs and reduce wildflower stands, growth, and bloom production. Hence, control of weeds is a necessity in successful establishment and maintenance of wildflowers.

II. Definition of the Problem

The most widely used initial weed control treatment for wildflower sites in North Carolina has been soil fumigation, typically with methyl bromide (Anon., 2003a). Methyl bromide is a broad-spectrum fumigant, killing not only weeds but also insects and pathogens. Methyl bromide effectively controls most weedy species, but there are some hard-seeded species, such as white clover and vetch species, that are not controlled. Additionally, weed seed may be moved into the wildflower beds after fumigation by wind or animals or the use of mulches containing weed seed. Hence, control by methyl bromide fumigation is sometimes supplemented with herbicides (Anon., 2003a). Unfortunately, there are few herbicides currently registered for this use. Additionally, wildflower tolerance to some of those herbicides is marginal; tolerance to most herbicides is unknown. Grassy species can be controlled with graminicides such as sethoxydim (Anon., 2003d). Control of dicotyledonous weeds, while maintaining wildflower tolerance, can be challenging. Hence, the NCDOT has continued to rely on fumigation as the cornerstone of its weed management program in wildflowers.

Methyl bromide is widely used in the production of vegetables, small fruits, and ornamentals, including wildflowers. It is injected into the soil as a gas. Because of the high volatility of the fumigant, the treated area is covered with plastic tarping to maintain a lethal concentration of the fumigant in the soil for a designated period of time. Much of the methyl bromide used for fumigation escapes into the atmosphere (Wang and Yates, 1998), where it contributes to ozone depletion (Albritton et al., 1998). The U.S. Environmental Protection Agency classed methyl bromide as an ozone-depleting substance in 1993.

Concern for the atmospheric ozone layer led 160 nations to agree to a phase-out of methyl bromide, starting with a 25% reduction in production in 1999 and a complete ban by 2005 (USDA-ERS, 2000). Loss of methyl bromide could seriously jeopardize the wildflower program unless suitable alternative control measures can be found.

III. Previous Research

A. Herbicides as an Alternative to Fumigation

Herbicides would appear to be a logical alternative to methyl bromide fumigation of wildflower planting sites. Fumigation with methyl bromide is very expensive; the cost of herbicides would be 5% or less of the cost of methyl bromide fumigation. Herbicides could be applied much more quickly and easier than fumigants, and NCDOT has the equipment and personnel to make such applications. This would eliminate having to contract with commercial applicators to fumigate. Moreover, the unsightly plastic tarp would be avoided.

Information on the use of herbicides in wildflowers is extremely limited. Herbicides that would potentially be used on wildflowers are the same as those used in agronomic and horticultural crops and in turf. Much of the needed information on the efficacy of such herbicides on weeds commonly found in North Carolina wildflower plantings can be gleaned from other sources, such as herbicide labels and experiments with crops. The major deficiency in the current knowledge base is wildflower tolerance of herbicides.

A thorough review of the scientific literature and postings on the internet produced very few reports concerning herbicide use on wildflowers. Derr (1993) compared tolerance of transplanted lanceleaf coreopsis, ox-eye daisy, Indian blanket, and purple coneflower to metolachlor applied alone and in combination with simazine, isoxaben, or oxadiazon. Seedlings of the four wildflower species were transplanted in the field and the herbicides were applied a few days after transplanting. Acceptable wildflower tolerance was noted with metolachlor and metachlor plus oxadiazon but not with metolachlor plus simazine or isoxaben. Wildflowers are direct-seeded along North Carolina's roadsides, hence Derr's information does not apply to preemergence applications that would be made at or shortly after planting. The information could, however, lend insight into wildflower response to the limited number of herbicides evaluated in situations were herbicides are applied postemergence to wildflowers to obtain preemergence weed control.

Kuhns et al. (1996) compared weed control and tolerance of five wildflower species to imazapic applied preemergence or postemergence. Imazapic, which is currently registered for use in wildflowers, applied preemergence gave excellent weed control (smooth pigweed, common yellow woodsorrel, green foxtail, common lambsquarters, common dandelion) whereas control was poor with postemergence application. Tolerance of cosmos, cornflower, corn poppy, sweet alyssum, and plains coreopsis was acceptable with preemergence and postemergence applications. Imazapic applied postemergence reduced wildflower height but did not reduce stands or bloom production.

White clover is a perennial that often encroaches into established wildflower plantings. In Georgia, Corley and Murphy (1994) found that winter application of quinclorac controlled white clover while causing no injury to cornflower or black-eyed susan and only temporary injury to lanceleaf coreopsis, California poppy, and Indian blanket.

Skroch and Gallitano (1991) evaluated 17 preemergence herbicides on ox-eye daisy, California poppy, nodding catchfly, annual phlox, and two primrose species. Of the 17 herbicides, they concluded that only metolachlor and napropamide were adequately safe on all six species. However, this work was conducted under conditions that likely cannot be extended to roadside plantings. The work was conducted in gallon-sized nursery pots with a pine bark/sand medium. Furthermore, their tolerance conclusions were based solely on wildflower emergence. Emerged wildflowers were counted and removed, hence there was no possibility to examine effects of the herbicides on wildflower growth and bloom production.

Skroch and Gallitano (1991) also evaluated nine herbicides or herbicide combinations applied in the fall to established ox-eye daisy beds. They did not specifically report on ox-eye daisy injury from the herbicides, but their data did show that most treatments increased ox-eye daisy bloom production, presumably due to control of weeds.

The most extensive study of wildflower tolerance and weed control with herbicides was conducted in North Carolina. The study was initiated by Harold Coble and completed by Fred Yelverton and Leon Warren at North Carolina State University. This project was funded by the NCDOT and ran from 1999 to 2002. In this study, response of 28 wildflower species to 21 soil-applied herbicides and 19 postemergence-applied herbicides was determined in a greenhouse experiment. Twenty-five species were included in a field study to examine tolerance to the same herbicides used in the greenhouse. The results have not been formally published, but they were summarized and critically reviewed by the author of the current proposal (York, 2003). Wildflower tolerance varied greatly among herbicides and species, but a number of herbicides were found to be adequately safe on wildflowers in the greenhouse. Fewer species were tolerant of postemergence herbicides although adequate tolerance to specific herbicides was noted in most species. Tolerance of 25 species to the same preemergence and postemergence herbicides was examined in a 2-year field study. Again, more species were tolerant to more soil-applied herbicides than was the case with postemergence herbicides. A considerable number of discrepancies were noted in tolerance to herbicides between the 2 years of the field study. Moreover, major inconsistencies were noted in conclusions from field experiments as compared with greenhouse experiments. The inconsistencies could be partly attributed to varying environmental conditions. However, it was concluded that inconsistent responses were likely inherent with wildflowers and that additional research was needed to expand the data base on wildflower tolerance to herbicides.

B. Fumigant Alternatives to Methyl Bromide

In contrast to the lack of information on herbicide use in wildflowers, much research has been conducted to seek fumigant alternatives to methyl bromide. This is because of the anticipated economic impact due to the ban on methyl bromide. Most of the methyl bromide used in the United States is applied preplant to vegetable and small fruit crops to control a broad spectrum of pathogens, insects, and weeds. Loss of methyl bromide will seriously impact production of these crops. Estimates of the economic impact on growers and consumers from loss of methyl bromide range from $0.5 billion to $1.5 billion annually (Anon., 1993; Carpenter et al., 2000). In light of this devastating effect on the fruit and vegetable industry, a major research effort is underway to find alternatives to methyl bromide.

Fumigants currently available include chloropicrin, 1,3-dichloropropene, dazamet, and metam-sodium. Methyl iodide is currently undergoing EPA review, with anticipated registration prior to the final phase-out of methyl bromide in 2005 (Anon. 2003b).

Chloropicrin is an effective fungicide, but it is weak on fungi and it is generally thought to not have the herbicidal properties of methyl bromide (Csinos et al. 1997, 2000; Himelrick and Dozier, 1991). Haar et al. (2003), however, reported similar control of several weed species with cloropicrin and methyl bromide. Fennimore et al. (2003) also reported significant activity on weed seed. 1-3-dichloropropene provides excellent control of nematodes and some soilborne insects, but little activity against weeds is obtained at registered rates (Noling and Becker, 1994).

Metam-sodium is a water-soluble, contact-type soil fumigant in a liquid formulation. When applied to soil, metam-sodium is degraded to methyl isothiocyanate (MITC), which is the primary toxic agent (Smelt and Leistra, 1974). Weed control is dependent upon contact of MITC with seed (contact defined as the product of concentration and time). Metam-sodium must be sealed in the soil to prevent rapid loss of MITC. It is generally accepted that the best method to seal it in is intermittent watering after application

(Sullivan, 2000). However, good results have been obtained by sealing the soil with a roller after incorporation with a roto-tiller (Hagland, 1999). Tarping is also an effective way to seal it in, with some research showing better weed control with tarping as compared to rolling (Hagland, 1999). Metam-sodium sealed in by rolling the soil is currently used on some roadside wildflower plantings by NCDOT.

Research has shown good weed control, usually equal to control by methyl bromide, by metam-sodium and metam-sodium/chloropicrin combinations (Csinos et al., , 1997, 2000; Dowler, 1999; Fennimore et al., 2003; Hagland, 1999; Seebold and Csinos, 2001; Sullivan, 2000). Moreover, metam-sodium is considerably more economical than methyl bromide (Carpenter et al., 2000).

Dazomet is a microgranular product that reacts with soil moisture to produce MITC. Weed control has been variable and generally less than with other fumigants (Miner and Worsham, 1990; Unruh et al., 2002). Moreover, dazomet's physical characteristics (ultra-fine powder) impose application limitations (extremely corrosive, vulnerable to drift, equipment must be sealed to limit spillage (Carpenter et al., 2000; Unruh et al., 2002).

Methyl iodide has been suggested as the most likely replacement for methyl bromide (Martin, 2003; Ohr et al., 1996). Methyl iodide is considered to be ozone safe (Albritton and Watson, 1992; Ohr et al., 1996) . It is quickly degraded in the troposphere via photolysis. Methyl iodide lasts in the atmosphere for only 2 to 8 days as compared to 2 years for methyl bromide (Chameides and Davis, 1980). As a result, it is unlikely to reach the stratosphere to participate in ozone depletion (Ohr et al., 1996; Solomon et al., 1994). Methyl iodide has the advantage of being a liquid at temperatures below 43 C whereas methyl bromide is a gas above 4 C (Zhang et al., 1998). Thus, methyl iodide is easier and safer to handle. It can be pumped using conventional equipment, resulting in less risk of worker exposure.

Methyl iodide is a suitable replacement for methyl bromide for control of insects, nematodes, and fungi (Becker et al., 1998; Hutchinson et al., 1999, 2000; Waggoner et al., 2000). Although research on weed control by methyl iodide has been much less extensive than research on disease control, methyl iodide appears to be an effective alternative to methyl bromide for weed control.

Zhang et al. (1998) reported the methyl iodide caused greater mortality to buried Italian ryegrass and velvetleaf seeds than did methyl bromide when the two were compared at equal molar concentrations. Moreover, methyl iodide performed more consistently across a range of soil textures than did methyl bromide. Control of purple nutsedge, yellow nutsedge, bermudagrass, alexandergrass, broadleaf signalgrass, Carolina geranium, cutleaf eveningprimrose, cudweed species, redroot pigweed, and morningglory species by methyl iodide has compared well with the control by methyl bromide (Unruh et al., 2002; Zhang et al., 1997). In California, a 50:50 mixture of methyl iodide plus chloropicrin at 350 lb/A and a 57:43 mixture of methyl bromide at 355 to 400 lb/A controlled common purslane, prostrate knotweed, common lambsquarters, carpetweed, prostrate spurge, and filaree species similarly Fennimore et al., 2001).

Webster et al. (2001) reported less control of purple nutsedge, bermudagrass, cutleaf eveningprimrose, Florida beggarweed, goosegrass, pink purslane, redroot pigweed, smallflower morningglory, and Texas panicum with methyl iodide compared to methyl bromide. However, the validity of the comparison is questionable since methyl bromide was injected with a chisel-type applicator whereas methyl iodide was applied via drip tape under the row of squash and pepper.

Methyl iodide is expected to be more expensive than methyl bromide, up to 50% more, but that cost may be offset by lower use rates. Some research has shown that it takes less methyl iodide to achieve the same level of weed control as with methyl bromide (Anon., 2003c; Unruh et al., 2002; Zhang et al. 1997). Moreover, recent research indicates use of virtually impermeable films (VIF) for tarping could further reduce the rate needed for pest control. Compared to the typically used low density polyethylene tarps commonly used in fumigation, VIF allows much less fumigant to pass through (Papiernik and Yates, 2001). Use of VIF in fumigation operations can result in better weed control and often allows reduced rates of fumigants (Fennimore et al., 2003; Gilreath et al., 2000, 2003; Martin, 2003).

IV. Research Objectives

1. Determine weed control and tolerance of multiple wildflower species to new and existing herbicides applied preplant incorporated/preemergence and postemergence during the establishment phase of wildflowers planted in the spring and fall.

2. Determine weed control and wildflower tolerance to herbicides applied to control emerged weeds or applied for residual control in established wildflower plantings.

3. Determine potential of specific herbicides applied to a fall or spring wildflower planting to carry over to wildflower species planted the following spring or fall, respectively.

4. Determine the efficacy, strengths and weaknesses, and costs of methyl iodide fumigation with tarping as compared with metam-sodium fumigation with the roto-vate/roll method.
5. Expand the current data base on weed control and wildflower tolerance to herbicides.

6. Extend acquired information to NCDOT personnel involved in wildflower production decisions via tours of field studies, printed materials, and further development of a computer decision aid for weed management in wildflowers.

V. Overall Work Plan

A. Design of Experiments and Methodology

The proposed studies will be conducted under field conditions. Most of the work, especially experiments dealing with herbicides used in establishing wildflowers and fumigant work, will be conducted on research stations operated by the North Carolina Department of Agriculture or North Carolina State University. Work with established wildflowers will be conducted primarily in wildflower plantings along highways. Interesting observations in the field may be followed up with greenhouse studies in a greenhouse on the North Carolina State University campus.

Fumigant studies will be on a scale large enough to permit commercial application equipment. Typical small-plot techniques will be utilized in herbicide evaluations, including herbicide application with CO_2-pressurized backpack sprayers. Experiments will be conducted at multiple locations. Treatments will be replicated and experimental designs will be selected as appropriate for the particular experiments. Data will be subjected to appropriate statistical analyses. Data collection will consist of visual estimates of stands, wildflower injury, bloom production, initiation of bloom and length of bloom, and weed control. Other measurements, such as stand counts, bloom counts, and plant heights, will be made as appropriate for particular studies.

B. Itemized Tasks

1. Tolerance and weed control with herbicides applied during fall establishment of wildflowers: Trials will be initiated in the falls of 2004, 2005, and 2006, with postemergence applications, data collection, and experiment maintenance continuing through the following springs.

2. Tolerance and weed control with herbicides applied during spring establishment of wildflowers: Trials will be initiated in the springs of 2005 and 2006 and continued through the summer with data collection and experiment maintenance as needed.

3. Fumigant evaluation: Trials will be established in the falls of 2004 and 2005, with data collection continuing through the following springs and summers. The trials may be continued in the fall of 2006, depending upon results from the previous years.

4. Tolerance and weed control with herbicides applied to established wildflowers: experiments will be conducted in established wildflower beds, with treatments applied during the fall and spring. Experiments will be initiated in the fall of 2004 and spring of 2005 and repeated through the fall of 2006.

5. Herbicide carryover potential in “double-cropped” wildflower plantings: Experiments with fall-planted wildflowers will be initiated in the falls of 2004 and 2005 and culiminate with data collection on spring- or summer-planted rotational species in the

falls of 2005 and 2006. Experiments with spring- and summer-planted species will be initiated in the summers of 2004, 2005, and 2006 and completed in the spring of the following years.

6. Update of computer decision aid: A computer decision aid developed at N. C. State, but still in preliminary stages, will be updated with new data as it becomes available. Most of the work will take place during the last year of the project.

7. Tours and training: The principal investigator will work with NCDOT personnel in planning and conducting tours, field days, etc., of field trials throughout the course of the research.

VI. Anticipated Results and Significance

Weed management in the North Carolina roadside wildflower program is a very complex issue because of the number of wildflower species planted, planting of multiple species at a site, frequent plantings within a site, the perennial nature of some of the plantings, the number of troublesome weeds encountered, and the impracticality of mechanical control. The matter will become even more complex when methyl bromide is banned in 2005. Very little is known about the use of herbicides in wildflowers and efficacy of alternative fumigants on the weeds typically encountered in North Carolina's wildflower plantings.

The primary product from the proposed research will be a data base on numerous herbicides that could potentially be used in wildflowers and recommendations for the use of suitable herbicides and alternative fumigants based upon scientifically sound research conducted to specifically address problems in the North Carolina program. The product will be used by personnel in the Roadside Environmental Unit involved in management decisions in wildflower production to maintain and enhance the highly popular wildflower program. The data base can also be used to support special use registrations for new herbicides found to be beneficial in the program.

VII. Technology Transfer

The knowledge and experiences gained from this research will be transferred to Roadside Environmental Unit personnel (the customers) via on-site visits, tours and field days, reports, training programs, and written and electronic guides and decision aids. Recommendations concerning use of herbicides as an alternative to methyl bromide will be made as appropriate, depending upon consistency of results, confidence in data, and product registrations.

VIII. Resources to be Supplied by NCDOT

NCDOT planting equipment will be used in establishing the research trials. Seed of the wildflower species used in this research will be furnished by NCDOT.

IX. Equipment and Facilities

Except for planting equipment, mentioned above, the performing organization will provide all necessary equipment for herbicide research. This includes various types of sprayers, trucks, tractors, trailers, and computer equipment for data analysis. Greenhouse facilities are available should it be deemed necessary to follow up on field observations with greenhouse studies. Fumigant application will require the services of a commercial applicator.

X. Time Requirements

The proposed research will cover a three-year period. This will allow for experiments to be repeated in time and conducted at multiple locations and under varying edaphic and environmental conditions. This is necessary for a valid data base. It is anticipated that the proposed research will require about 20% of the principal investigator's time and 75% of a research technician's time.

XI. Qualifications and Accomplishments of Researcher

The researcher earned a PhD degree in weed science and has 25 years of experience in applied weed management research and extension as a faculty member in the Crop Science Department at North Carolina State University. He has developed a nationally recognized program in weed management in agronomic crops. He is author or co-author of 68 manuscripts in refereed scientific journals, 5 book chapters, and 210 extension publications. In addition to research and extension responsibilities, he has taught a weed management course for 15 years and is actively involved in graduate student education. His accomplishments and service to the weed science community have been recognized with a number of awards, including the Outstanding Extension Award from the Weed Science Science Society of America, the Distinguished Service Award and the Outstanding Young Weed Scientist Award from the Southern Weed Science Society, and the Cotton Extension Education Award from the Cotton Foundation. He was recently appointed as a William Neal Reynolds Distinguished Professor at North Carolina State University.

XII. Other Commitments of Researcher

The researcher is currently responsible for state-wide research and educational programs on applied weed management in cotton, corn, soybeans, and small grains in North Carolina.

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